Evaluating and improving the results of air quality models in Texas using TES, AIRS and other satellite data

Greg Osterman

TES Science Team

Jet Propulsion Laboratory/California Institute of Technology

AIRS Science Team Meeting

- Collaborate with the Texas Commission on Environmental Quality (TCEQ) to improve the modeling of ozone episodes in Texas
  - Meteorological and air quality models are primary tool for developing emission strategies to bring TX into attainment with EPA Standards
- What we are doing:
  - ☞ Applications:
    - ➢ Using chemical transport model results as lateral and vertical boundary conditions for the TCEQ air quality model (CAMx)
    - ➢ Using TES (O3, CO, Sea Surface Temperature), AIRS (Temperature, H2O, CO), AMSR-E (Sea Surface Temperature) for benchmarking MM5 and CAMx model results
  - 📖 Science Studies:
    - ➢ Evaluating the effects of transport of pollutants originating outside the state boundaries
    - ➢ Nighttime ozone over Texas

- Collaborate with the Texas Commission on Environmental Quality (TCEQ) to improve modeling of ozone episodes in Texas

  – Meteorological and air quality models are primary tool for developing emission strategies to bring TX into attainment with EPA Standards

- What we are doing:

  ✎ Applications:

  ➤ Using chemical transport model results as lateral and vertical boundary conditions for the TCEQ air quality model (CAMx)

  ➤ Using TES (O3, CO, Sea Surface Temperature), AIRS (Temperature, H2O, CO), AMSR-E (Sea Surface Temperature) for benchmarking MM5 and CAMx model results

  Direct use of satellite data to benchmark model results used in making air quality policy decisions

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California Institute of Technology

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- Collaborators:
  - Mark Estes, Clint Harper, Weining Zhao, Doug Boyer, Jim Smith (TCEQ)
  - Jay Al-Saadi (NASA Langley Research Center)
  - Brad Pierce (NOAA/NESDIS)
  - Kevin Bowman, Brian Kahn, Bill Irion (JPL)
  - Wallace McMillan (UMBC)

- Thank you to Annmarie Eldering and Reinhard Beer for allowing me to continue this work between proposal calls

National Aeronautics and Space
Administration
Jet Propulsion Laboratory
California Institute of Technology
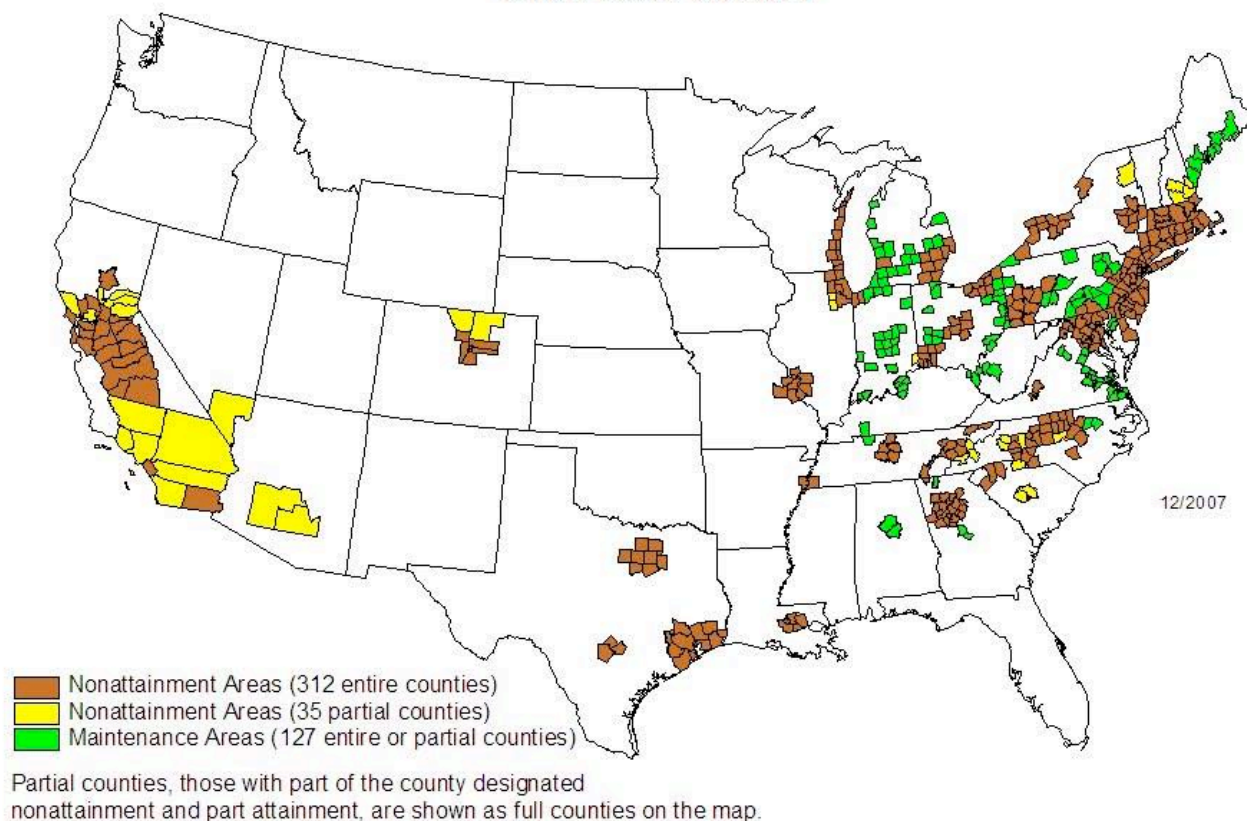
Federal Clean Air Act

- Federal Clean Air Act is the legal foundation for the national air pollution control program and gives the EPA the power to:
  - Establish national air quality standards
  - Monitor achievement of goals outlined in SIP
- EPA Eight-Hour Ozone Standard is at 0.08 ppm (0.075 ppm as of March12, 2008)
  - An area violates the standard when the 3-year average of each year's 4th highest reading at a monitor equals or exceeds 85 ppb
- State Implementation Plans:
  - An enforceable plan developed at the state level that explains how the state will comply with the Federal Clean Air Act
  - Must be submitted by any state that has areas designated as in nonattainment of federal air quality standards
  - Contains information on control strategies for bringing designated areas back into attainment
- Implications of nonattainment
  - Health implications of ozone pollution
  - Potential loss in billions of dollars economic development for the state
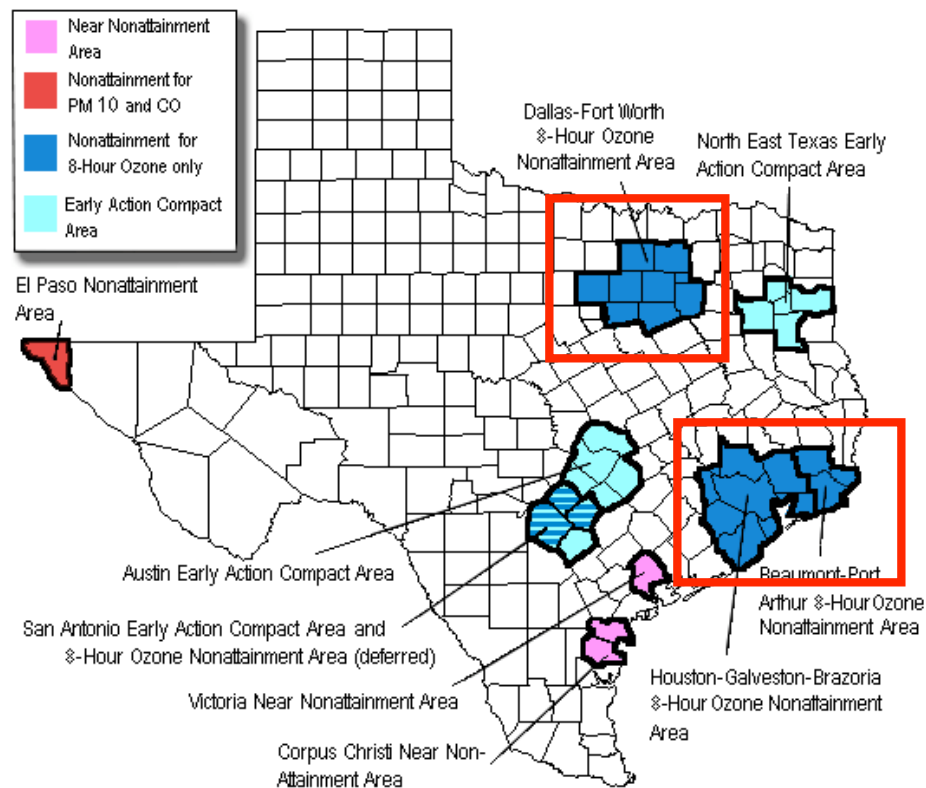
Nonattainment and Maintenance Areas in the U. S.
8-hour Ozone Standard

12/2007

■ Nonattainment Areas (312 entire counties)
■ Nonattainment Areas (35 partial counties)
■ Maintenance Areas (127 entire or partial counties)

Partial counties, those with part of the county designated
nonattainment and part attainment, are shown as full counties on the map.

Texas Areas of Nonattainment

- Focus of proposed work:
  - Houston/Galveston/Brazoria 8-Hour Ozone Designation: Moderate
  - Dallas/Ft Worth 8-Hour Ozone Designation: Moderate
  - SIP Revisions for both areas due June 15, 2007
- Areas that may be in non-attainment of new EPA Standard:
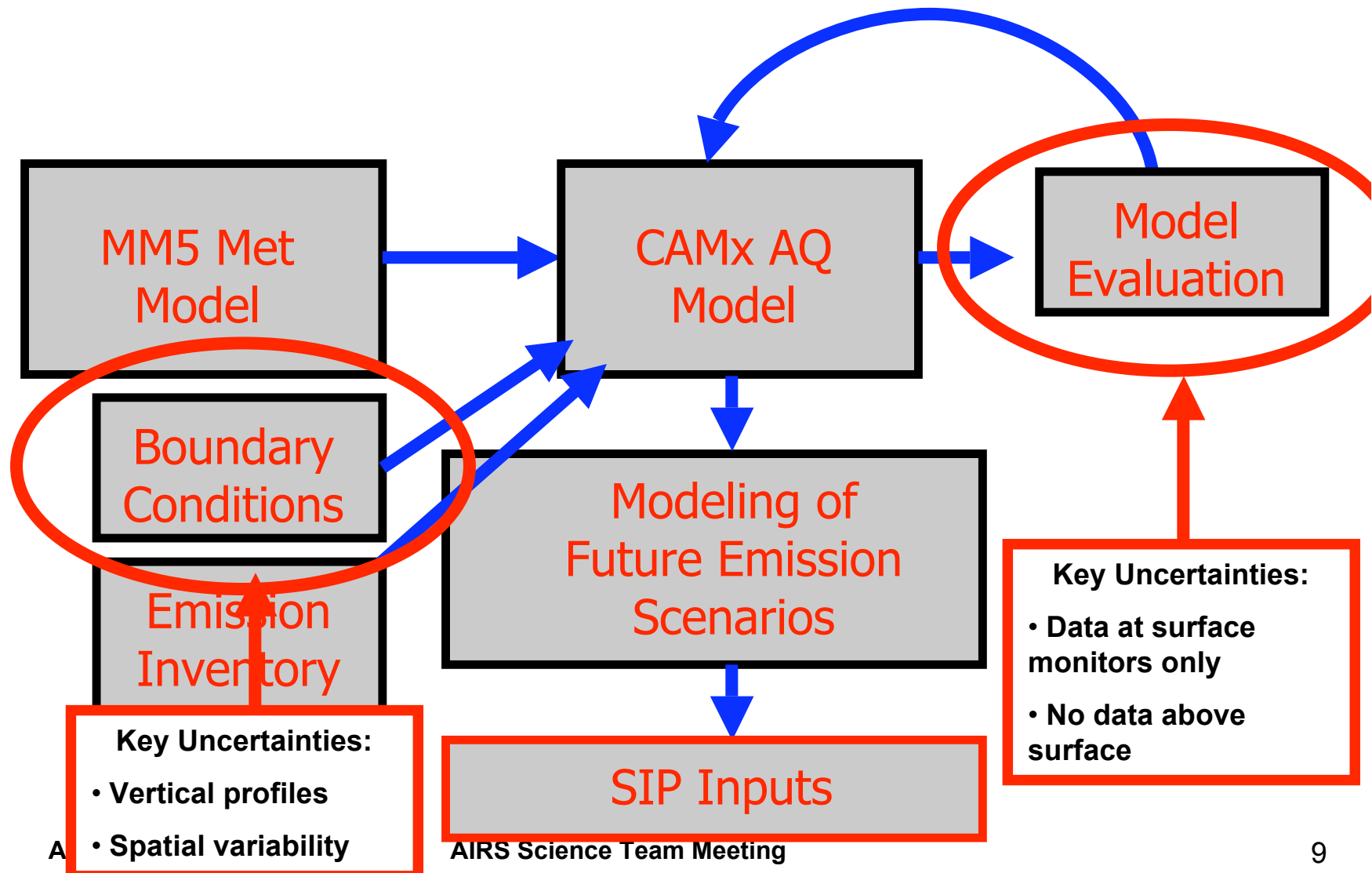 - Austin/San Antonio
  - Tyler/NE Texas
  - El Paso

Near Nonattainment Area
Nonattainment for PM 10 and CO
Nonattainment for 8-Hour Ozone only
Early Action Compact Area

Dallas-Fort Worth 8-Hour Ozone Nonattainment Area
North East Texas Early Action Compact Area
El Paso Nonattainment Area
Austin Early Action Compact Area
San Antonio Early Action Compact Area and 8-Hour Ozone Nonattainment Area (deferred)
Victoria Near Nonattainment Area
Corpus Christi Near Non-Attainment Area
Beaumont-Port Arthur 8-Hour Ozone Nonattainment Area
Houston-Galveston-Brazoria 8-Hour Ozone Nonattainment Area
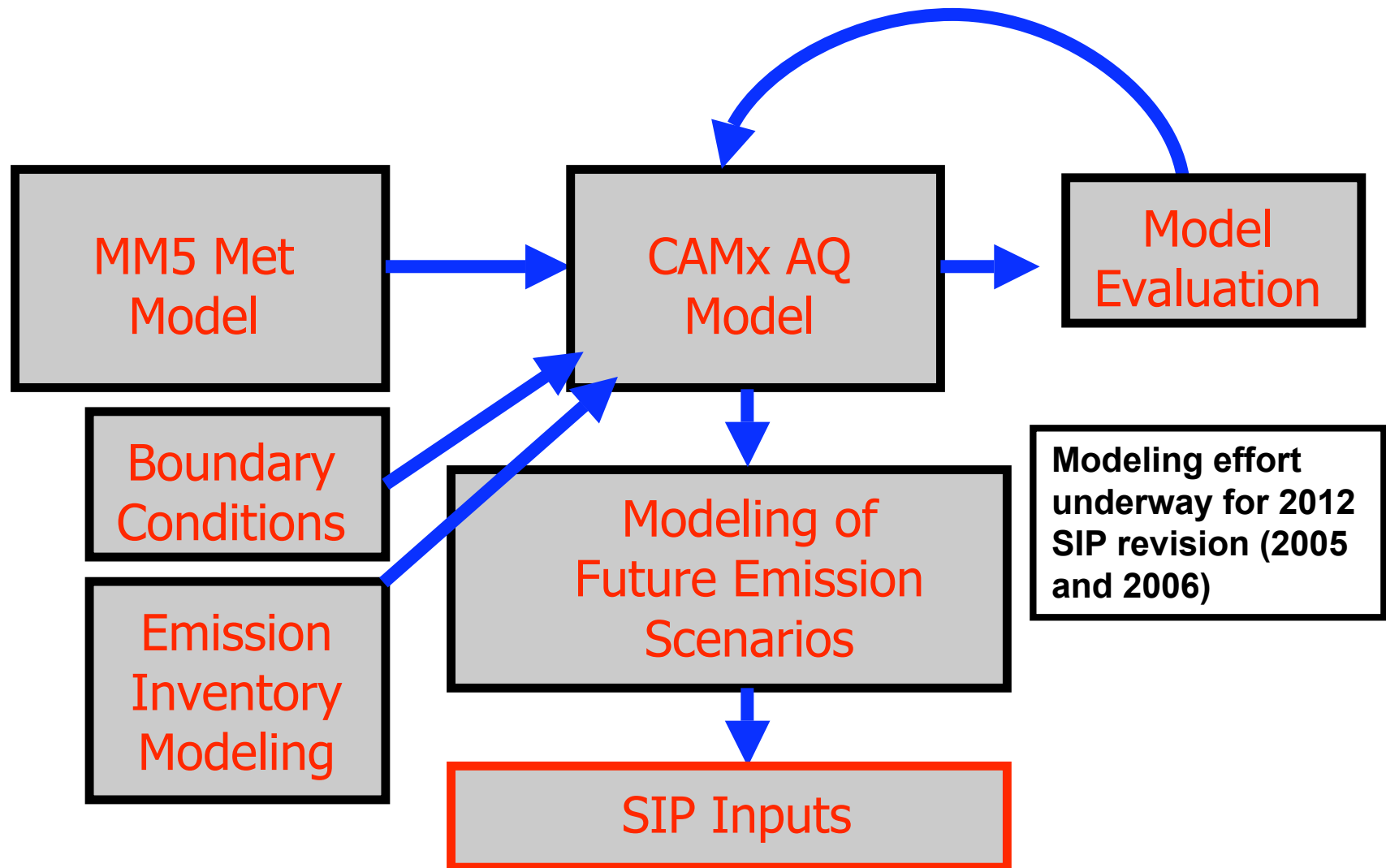
TCEQ Modeling Process for SIP Input
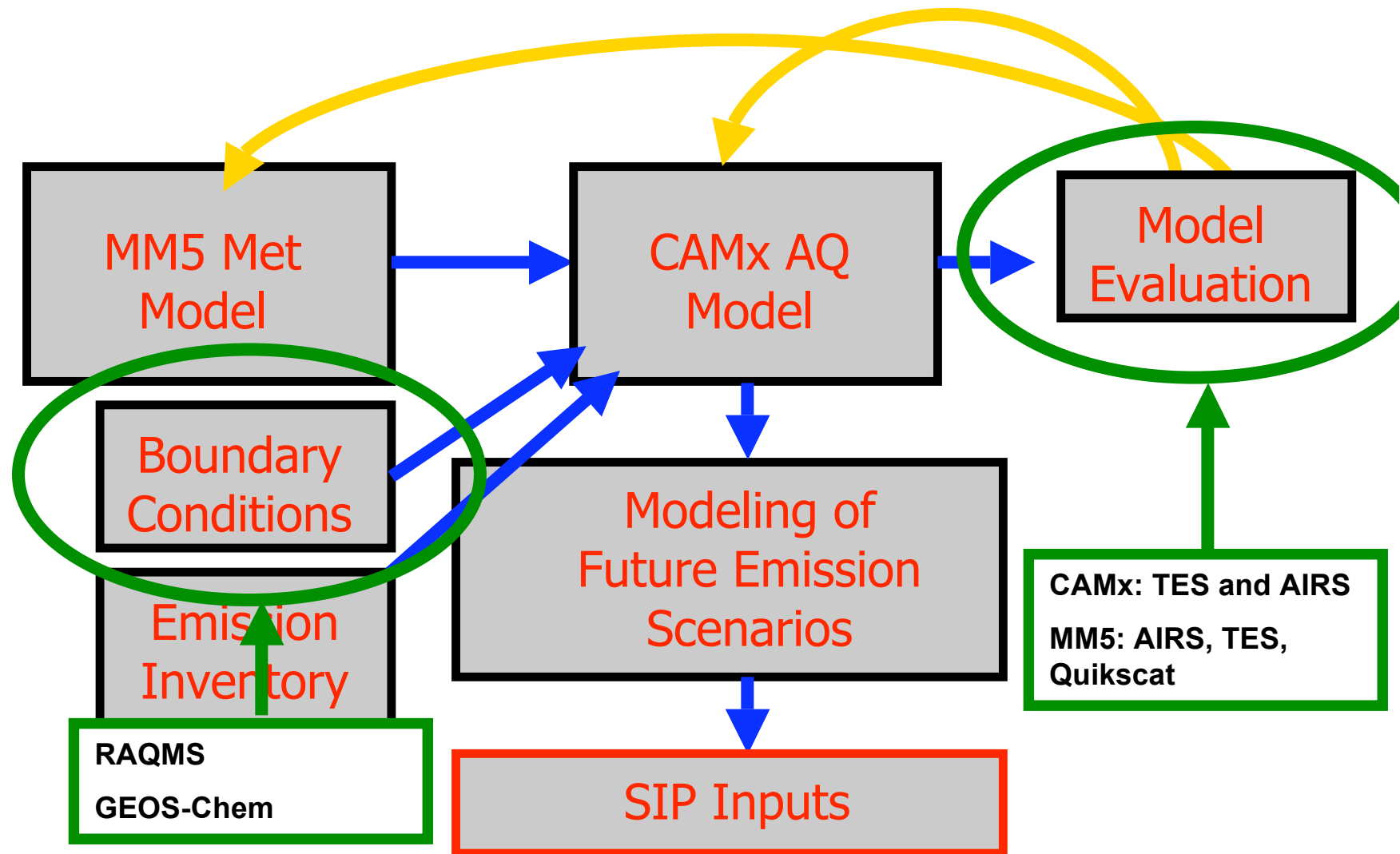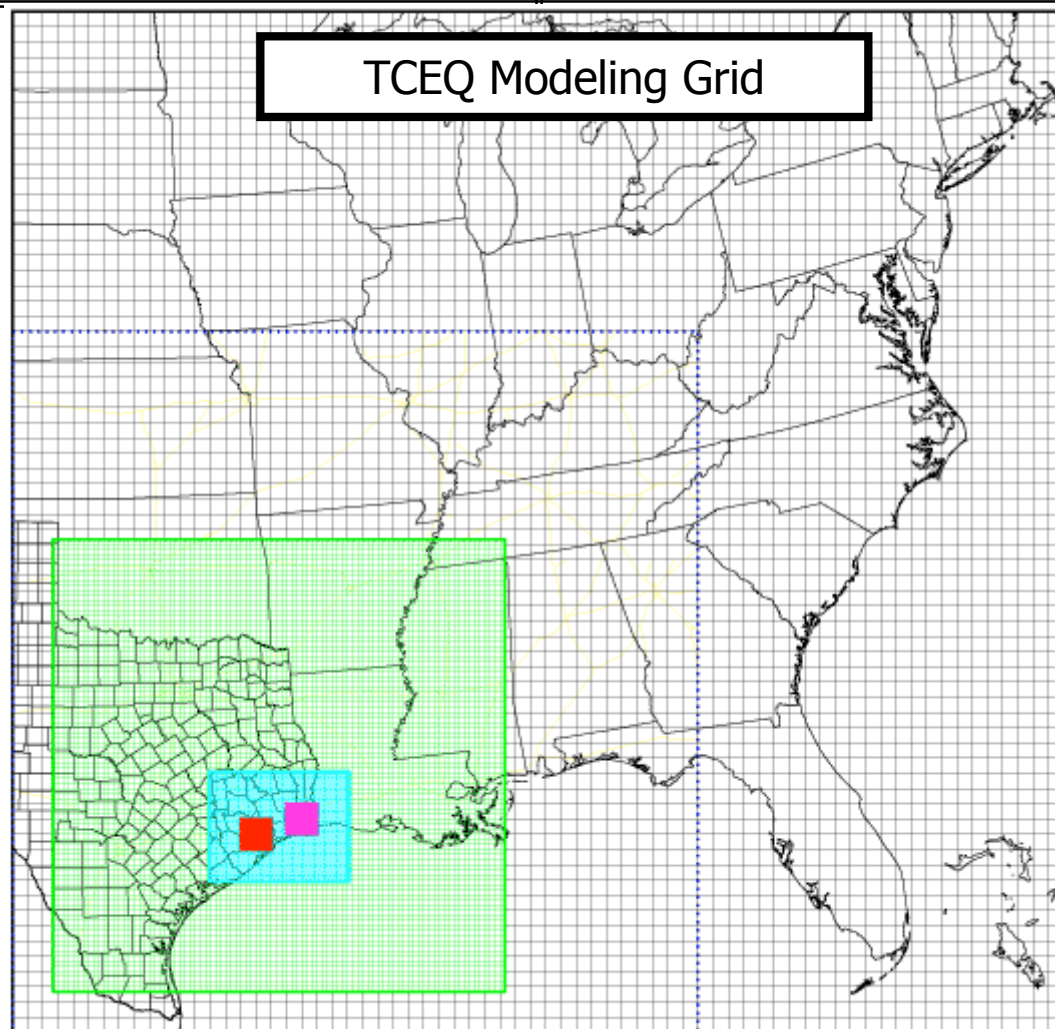
April 16, 2008   AIRS Science Team Meeting   8

TCEQ Modeling Process for SIP Input

TCEQ Modeling Process for SIP Input

MM5 Met Model

CAMx AQ Model

Model Evaluation

Boundary Conditions

Emission Inventory

Modeling of Future Emission Scenarios

RAQMS

GEOS-Chem

SIP Inputs

CAMx: TES and AIRS

MM5: AIRS, TES, Quikscat

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Air Quality Model Evaluation

TCEQ Modeling Grid

East US (8-Hour)   Regional (1-Hour, MCR)   East Texas   HGHBBPAA   HGB   BPA

- TCEQ uses nested CAMx model runs
  - 36 × 36 km
  - 12 × 12 km
  - 4 × 4 km

- Currently modeling 5 time periods during 2005 & 2006

- Current boundary conditions are based on ground monitor data from EPA

- ~ 200 ground monitors in Texas (25 in Houston Area)
  - Primary model evaluation data
  - Mostly located in urban areas
  - No data over the Gulf of Mexico

Air Quality Model Evaluation

TCEQ Modeling Grid

East US (8-Hour)   Regional (1-Hour, MCR)   East Texas   HGBBRA HGB BPA
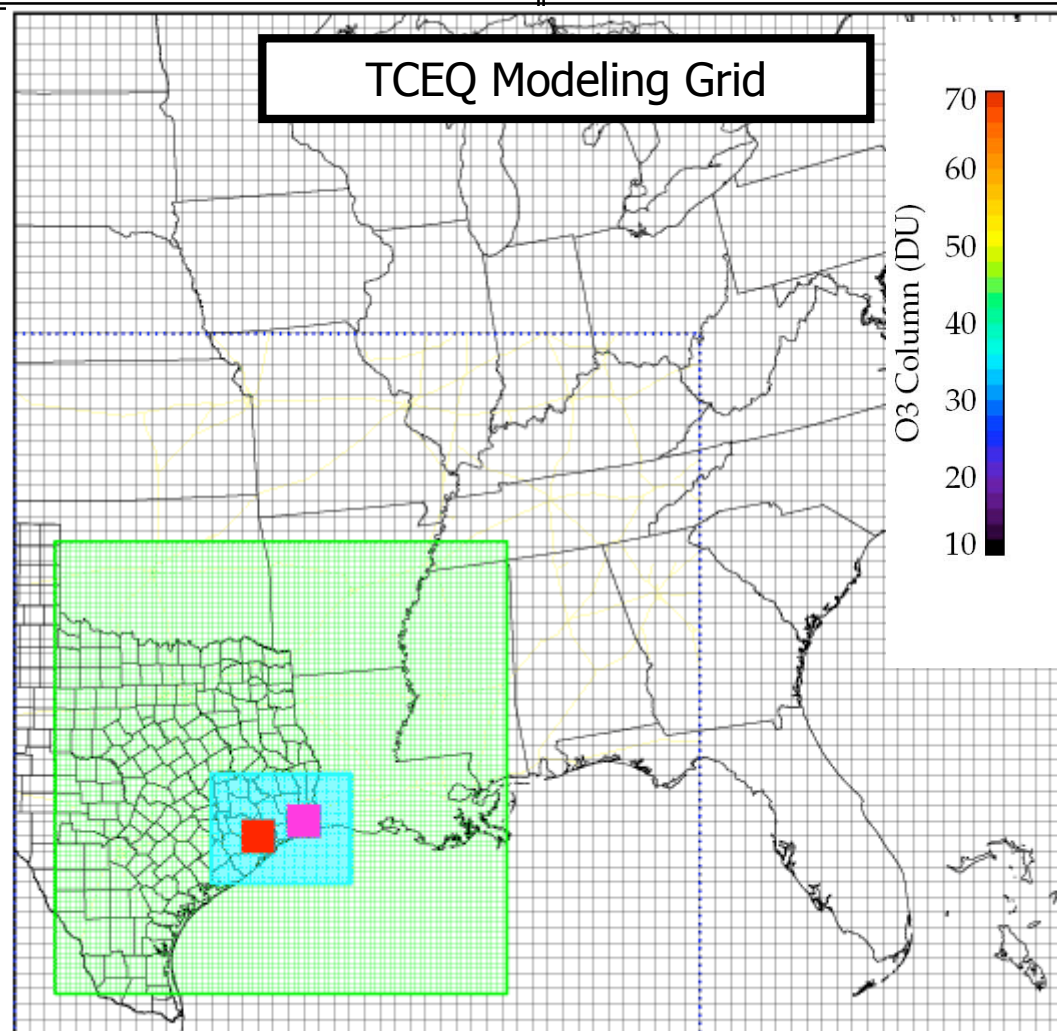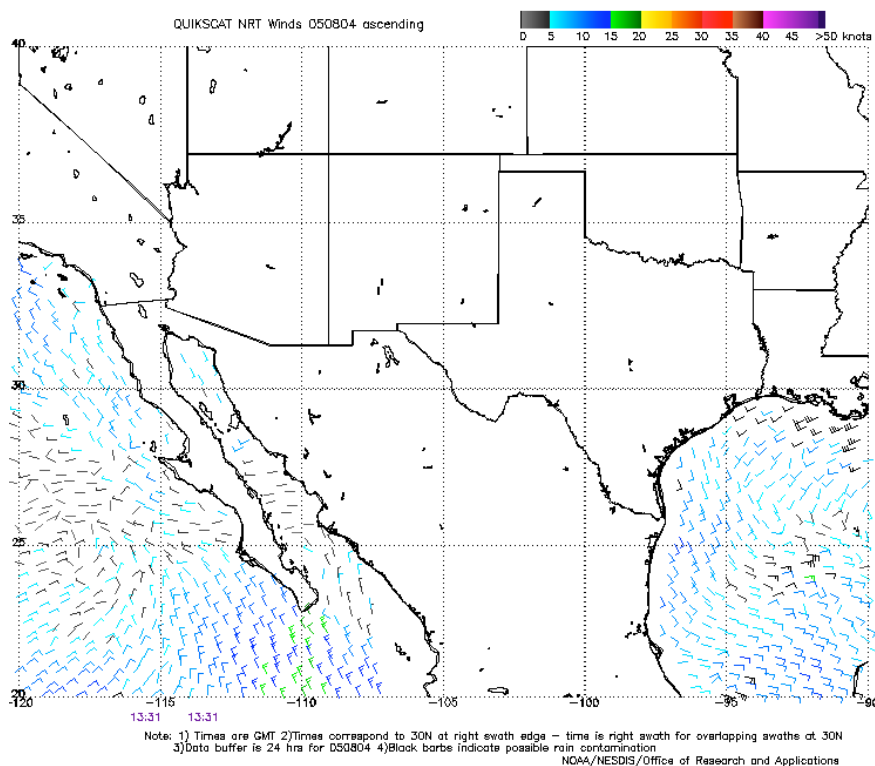
- TES can provide vertically resolved information on ozone and carbon monoxide in the troposphere
- Information in rural areas away from surface monitors
- Information over the Gulf
- AIRS CO provides better spatial resolution and vertical information

Air Quality Model Evaluation

TCEQ Modeling Grid

O3 Column (DU)

East US (8-Hour)   Regional (1-Hour, MCR)   East Texas   HGBPA   HGB   BPA

TES Observations 2006

- TES can provide vertically resolved information on ozone and carbon monoxide in the troposphere
- Information in rural areas away from surface monitors
- Information over the Gulf
- AIRS CO provides better spatial resolution and vertical information
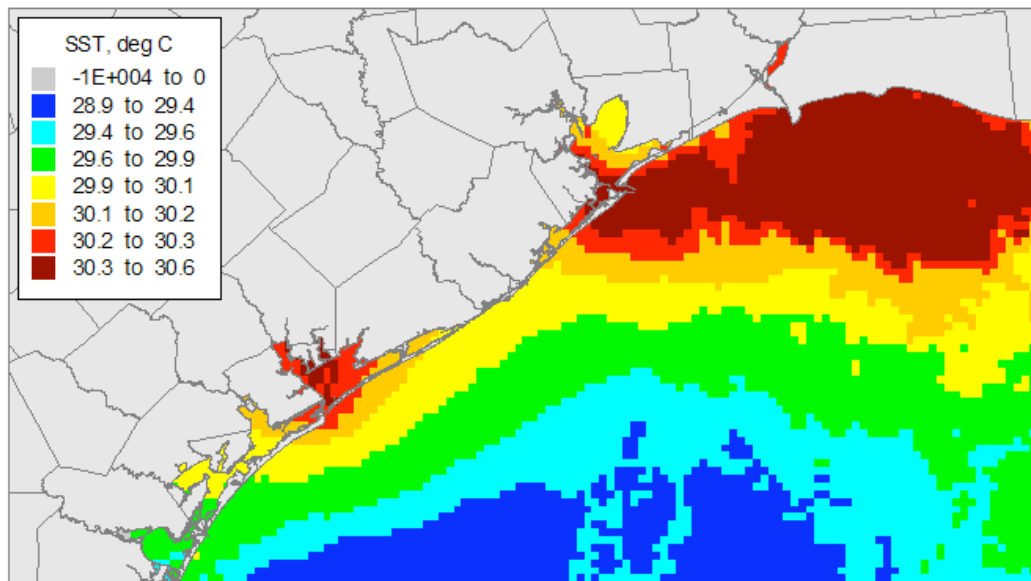
Meteorological Model Evaluation

QUIKSCAT NRT Winds 050804 ascending

0 5 10 15 20 25 30 35 40 45 >50 knots

13:31   13:31

Note: 1) Times are GMT 2)Times correspond to 30N at right swath edge – time is right swath for overlapping swaths at 30N 3)Data buffer is 24 hrs for DS0804 4)Black barbs indicate possible rain contamination

NOAA/NESDIS/Office of Research and Applications

- Houston air quality is tied to the wind patterns onto and from the Gulf of Mexico

- Sea surface temperature and winds in the Gulf are key variables that are not routinely validated within the TCEQ modeling system

- Plan to provide Quikscat data to TCEQ for use in MM5

- Winds over land?

Meteorological Model Evaluation

SST at 4Km Resolution 2005-218-09

SST, deg C
-1E+004 to 0
28.9 to 29.4
29.4 to 29.6
29.6 to 29.9
29.9 to 30.1
30.1 to 30.2
30.2 to 30.3
30.3 to 30.6

- TCEQ and the University of Houston have incorporated the GOES sea surface temperature product into MM5
- Took the hourly GOES product on 6 km grid and placed it on MM5 grids (108, 36, 12 and 4 km)
- Evaluation of data set is needed
  - TES SST product
  - AMSR-E SST product
- Evaluation of MM5 temperature profiles is also needed
  - AIRS Temperatures
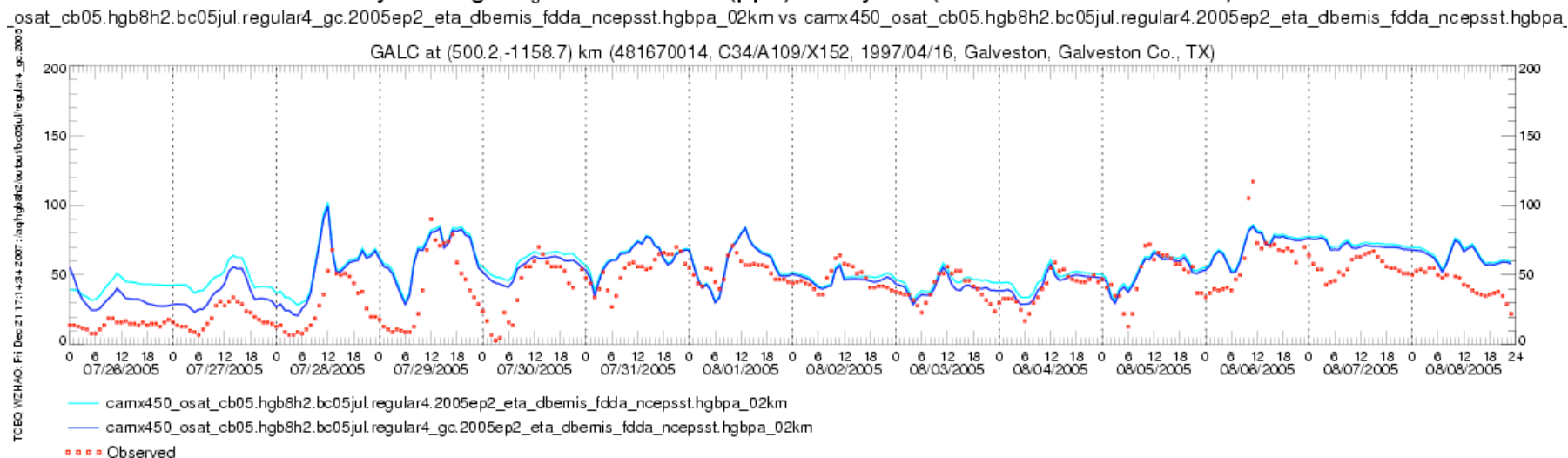
Preliminary Results - Conroe

Hourly Average O_3 Concentration (ppb) at Layer 1 (07/26/2005-08/08/2005)
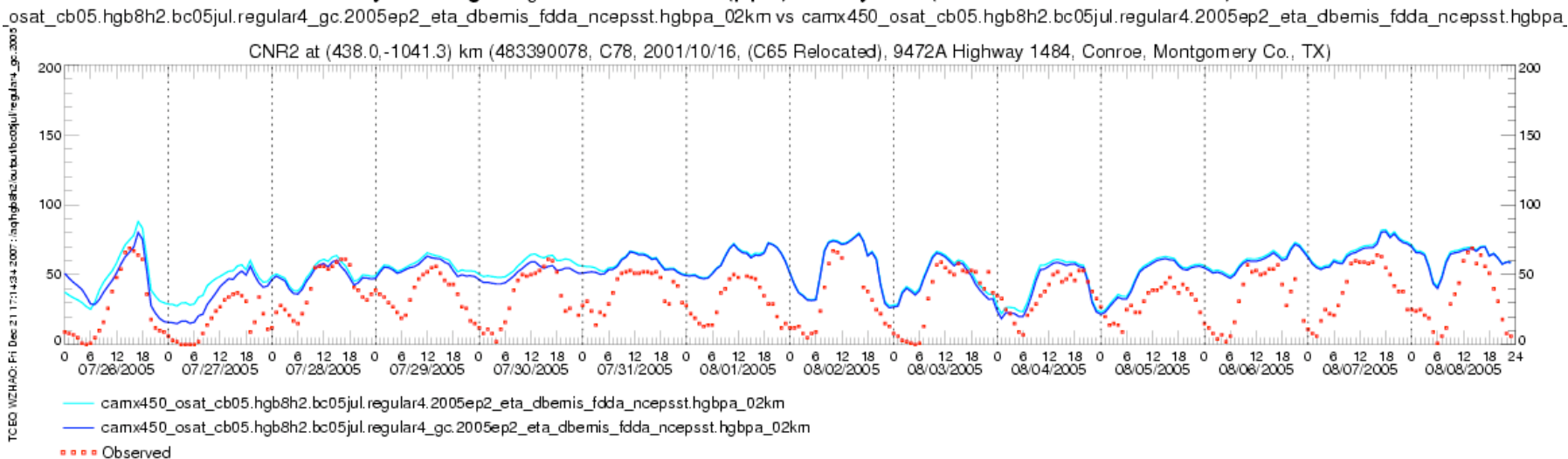
- Used GEOS-Chem Near Real Time results for time period July 24 – August 8, 2005 to provide boundary conditions in the troposphere for CAMx model
- Small improvement for July 29-30 in Conroe for comparisons with surface monitors
- Learning the best way to implement the use of GEOS-Chem
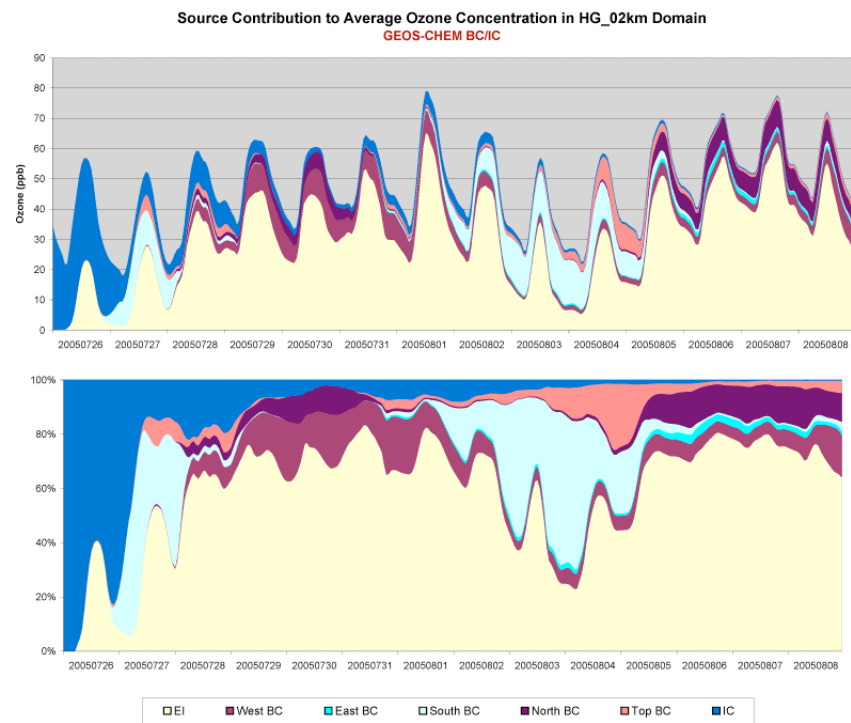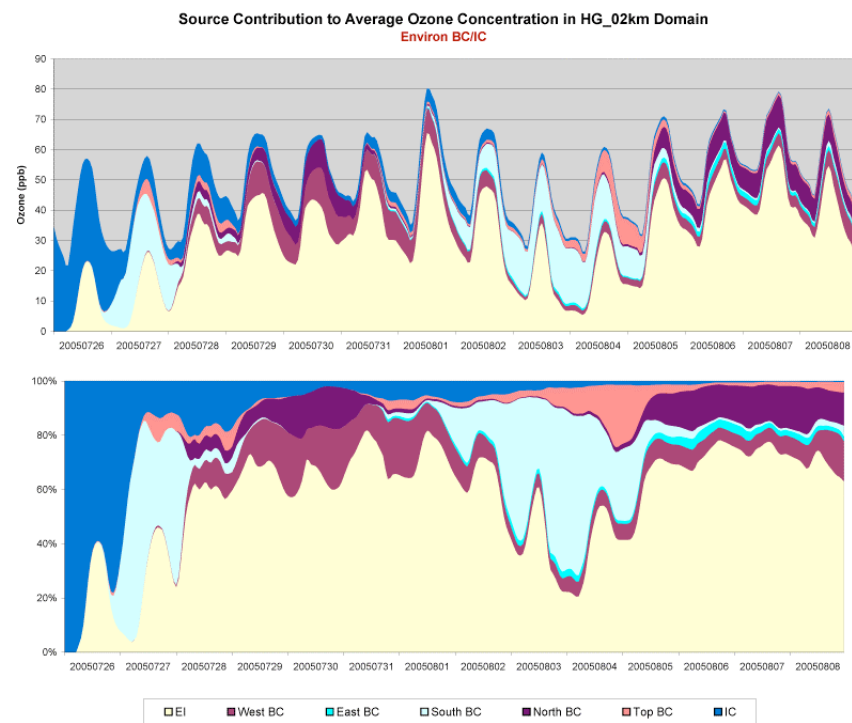- Expect improvement in model values of ozone above the boundary layer (not validated yet)

Preliminary Results - Galveston

Hourly Average O_3 Concentration (ppb) at Layer 1 (07/26/2005-08/08/2005)

_osat_cb05.hgb8h2.bc05jul.regular4_gc.2005ep2_eta_dbemis_fdda_ncepsst.hgbpa_02km vs camx450_osat_cb05.hgb8h2.bc05jul.regular4.2005ep2_eta_dbemis_fdda_ncepsst.hgbpa_

GALC at (500.2,-1158.7) km (481670014, C34/A109/X152, 1997/04/16, Galveston, Galveston Co., TX)

camx450_osat_cb05.hgb8h2.bc05jul.regular4.2005ep2_eta_dbemis_fdda_ncepsst.hgbpa_02km
camx450_osat_cb05.hgb8h2.bc05jul.regular4_gc.2005ep2_eta_dbemis_fdda_ncepsst.hgbpa_02km
Observed

- Used GEOS-Chem Near Real Time results for time period July 24 – August 8, 2005 to provide boundary conditions in the troposphere for CAMx model
- Small improvement for July 29-30 and August 3-4 in Galveston for comparisons with surface monitors
- Learning the best way to implement the use of GEOS-Chem
- Expect improvement in model values of ozone above the boundary layer (not validated yet)

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Tropospheric Emission Spectrometer
Source Apportionment –
Preliminary Result

Source Contribution to Average Ozone Concentration in HG_02km Domain
Environ BC/IC

Source Contribution to Average Ozone Concentration in HG_02km Domain
GEOS-CHEM BC/IC

Status of Work with TCEQ

- Completed:
  - Developed work plan for collaboration
  - Provided initial boundary conditions for July-August 2005 time period (GEOS-Chem)
- Next Steps:
  - Format RAQMS analyses for 2006 time periods as boundary conditions
  - Beginning evaluation of July-August 2005 CAMx model results with TES data
  - Evaluation of July-August 2005 MM5 temperature profiles with AIRS data
  - Evaluation of GOES/MM5 sea surface temperature with TES and AMSR-E
  - Provide Quikscat data for use in TCEQ modeling
  - Proposal – ROSES 2008 Applied Science Program (Air Quality Decision Support)
  - Transport studies from Texas Air Quality Study II (AIRS/TES/RAQMS/OMI)
    - August 23, 2006 – Osterman et al.
    - August 30, 2006 – McMillan et al.

Status of Work with TCEQ

- Longer term:
  - Add additional data sets (OMI NO2, …)
  - Fire effects in boundary conditions
  - Clouds

➢ CAMx is used by many state/local air quality boards
  - In contact with the state of California
  - Work done with TCEQ can be modified to work with other air quality models (CMAQ)
  - Climate change and future air quality

National Aeronautics and Space Administration
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California Institute of Technology

Tropospheric Emission Spectrometer
CA 2010 Air Quality and
Climate Mission (Proposed)

- Science Questions:
  - What are the important transport corridors for key chemical species within California, and under what conditions is that transport important?
  - What are the sources and physical mechanisms that contribute to high ozone concentrations aloft that have been observed in Central and Southern California?
  - What are the most important chemical processes occurring during night, particularly with respect to reactions of nitrogen oxides? What is needed to improve air quality modeling of nighttime chemistry?
  - What are proper oceanic boundary conditions for coastal and regional atmospheric chemistry modeling? Are there variations in oceanic boundary conditions in northern and central California vs. the southern part of the state? What physical and chemical changes occur as a parcel of air moves from off-shore, through the shore zone, and inland?
- Can apply lessons learned from Texas AQS II, work with TCEQ and California portion of ARCTAS
  - Air quality studies and applications
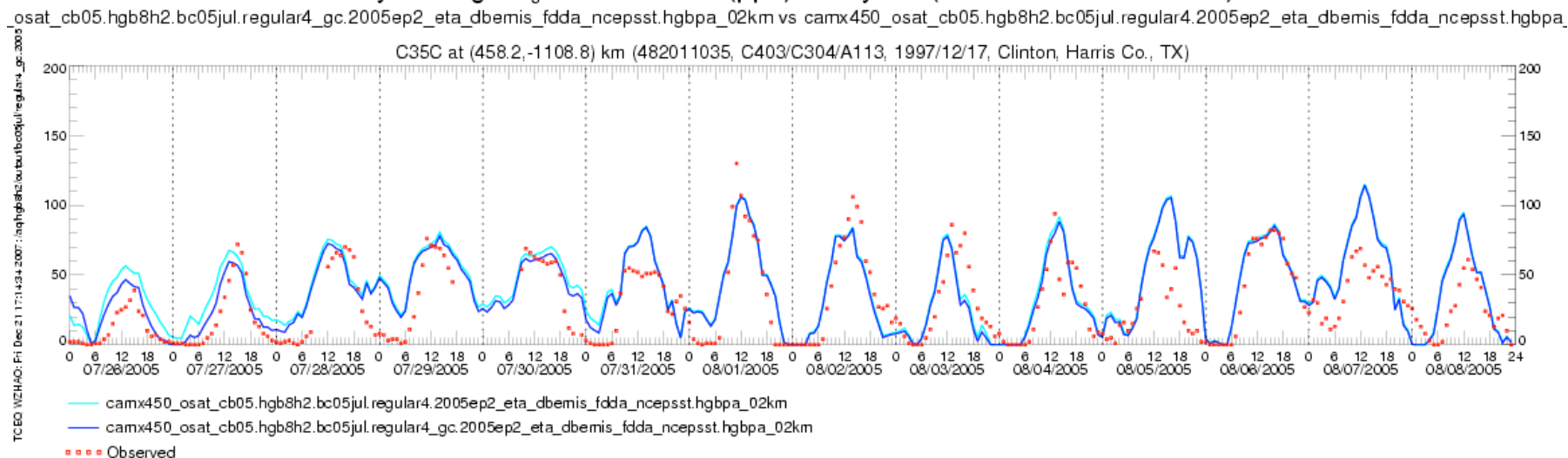 - Climate related analyses of TES radiances and tropospheric ozone

Extra

Preliminary Results - Clinton

Hourly Average O₃ Concentration (ppb) at Layer 1 (07/26/2005-08/08/2005)

- Used GEOS-Chem Near Real Time results for time period July 24 – August 8, 2005 to provide boundary conditions in the troposphere for CAMx model
- Small improvement for July 30-31 in Clinton for comparisons with surface monitors
- Learning the best way to implement the use of GEOS-Chem
- Expect improvement in model values of ozone above the boundary layer (not validated yet)

Goal 1: Use of satellite data (TES and OMI, and ozone sondes) to augment EPA activities (surface monitors, health data and models) in trying to mitigate the health effects of ozone episodes along the US-Mexico Border

Goal 2: Work with EPA to understand the strengths of Aura satellite data for understanding air pollution events

Preliminary Result: Improvements in modeling of free troposphere by air quality models (CMAQ)

Result: A project report is being finalized, work has been distributed widely in EPA

TES data helped improve the model with mid-tropospheric ozone

CMAQ=Community Multi-scale Air Quality Modeling System

Collaboration with EPA Region 9, JPL, UC-Berkeley, NASA Ames RC, Arizona State University

EPA Region 9 Advanced Monitoring Initiative: US – Mexico Border Pollution

CMAQ Prior to use of TES

$y = 0.0207 \cdot x + 63.7$
$R = 0.28$

CMAQ Using TES Boundary Conditions

$y = 0.337 \cdot x + 80$
$R = 0.69$
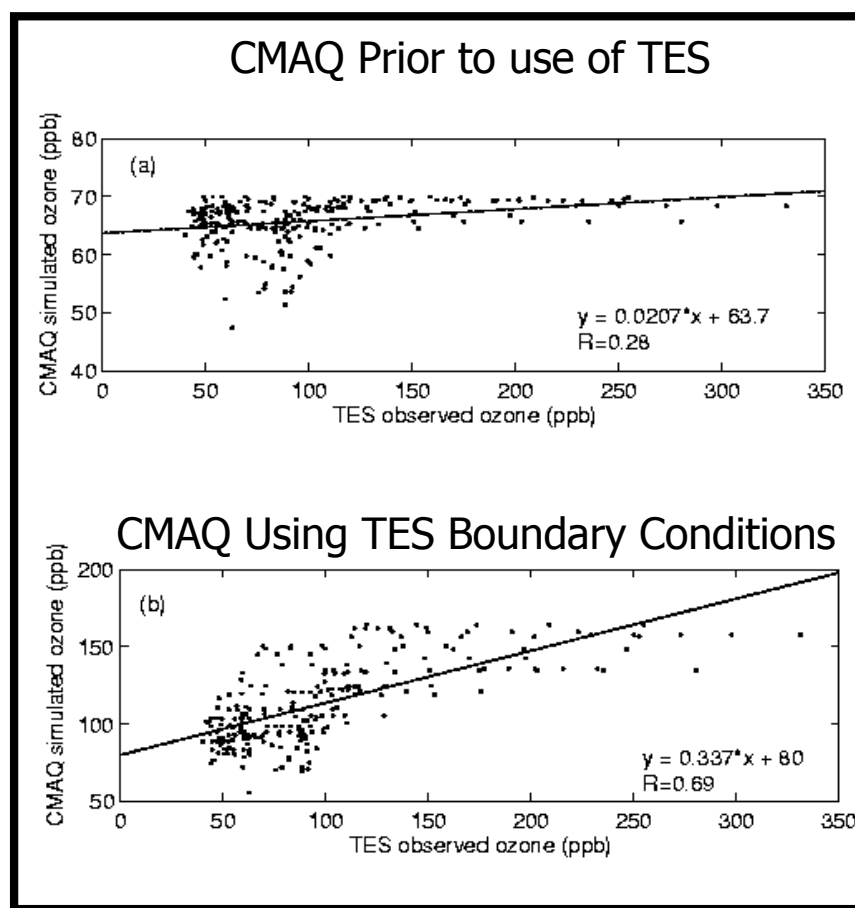
Tropospheric Emission Spectrometer
Using Satellite Data to Study Air Pollution and Potential Health Impacts - Continued

Aura Contribution: Using OMI/MLS products to map tropospheric ozone along with the ability of TES to provide vertical information on ozone and carbon monoxide in the troposphere to help the EPA to understand air pollution events

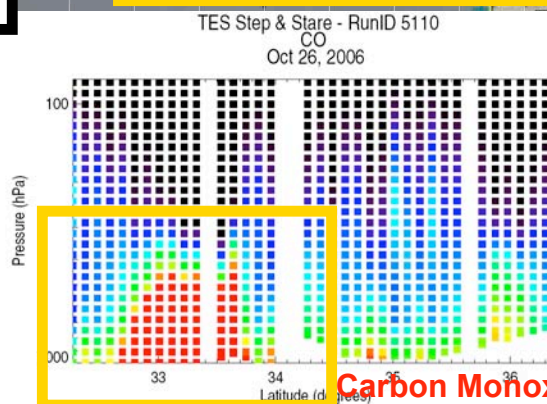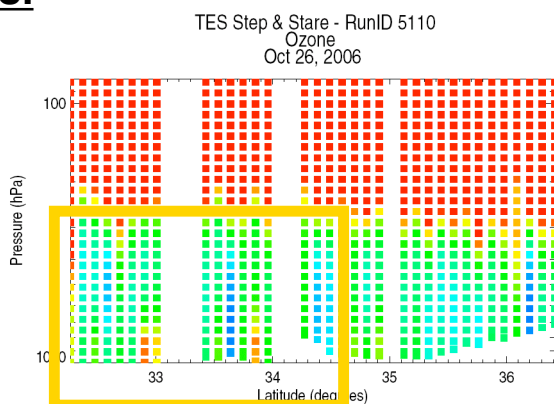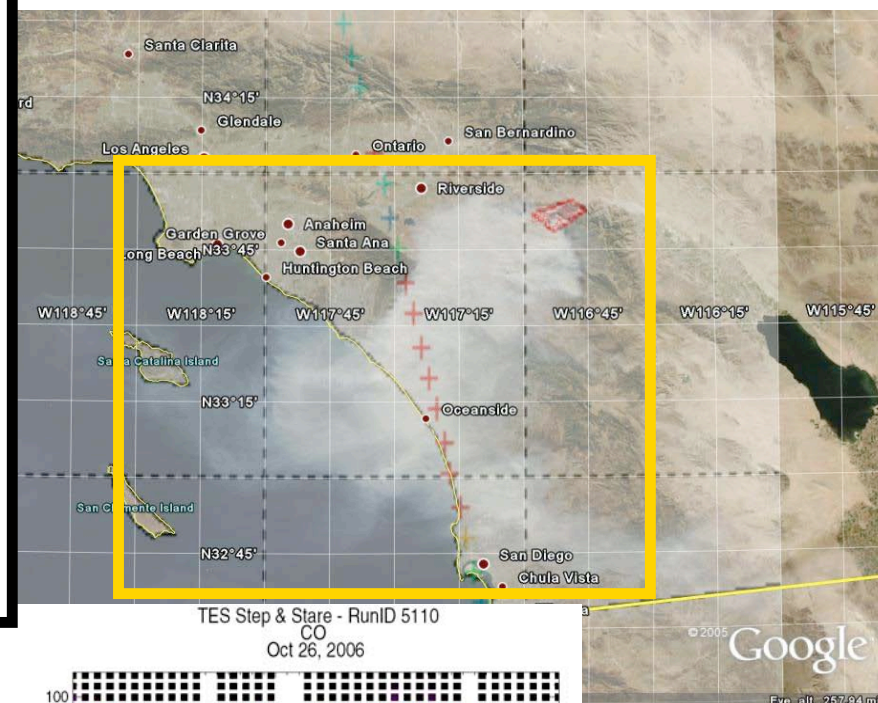**TES Contribution**: TES provided special observations across the US/Mexico border near San Diego and El Paso

Future Work: The work in this project is a first step and provides insight into how the NASA satellite data might be used with EPA tools and health data for studying air pollution events and their health impacts

TES Step & Stare Nadir Retrieval Result: Ozone
Cross Section Along Orbit Track: RunID=5395, Seq=1-1, Scan=0-39, UTCtime=21:06:45-21:11:06

Ozone Volume Mixing Ratio (ppb)
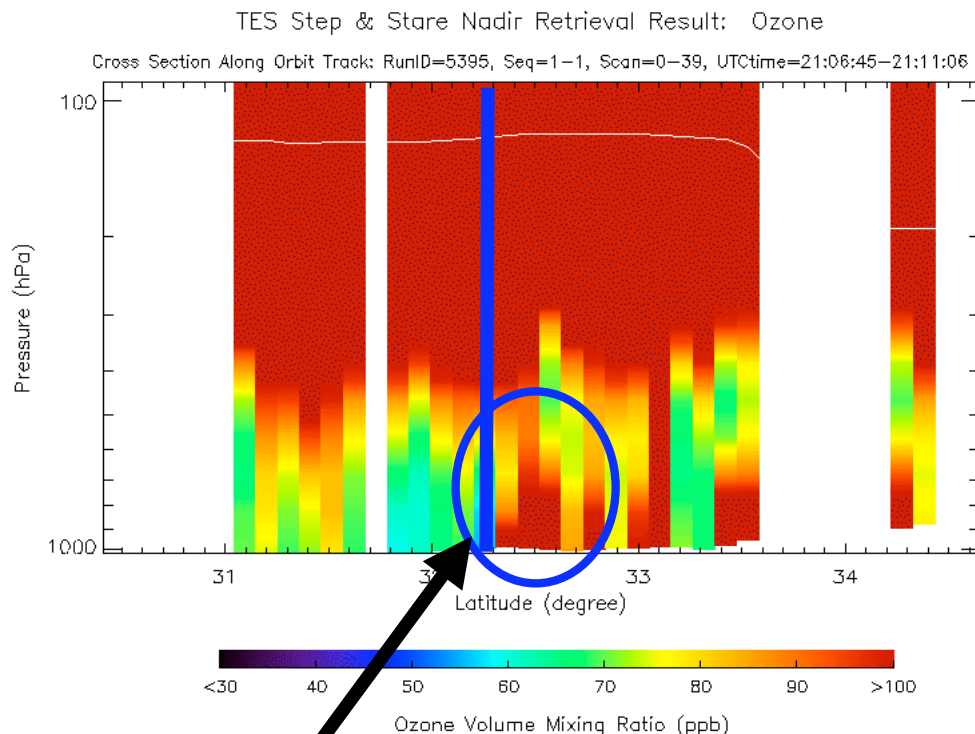
TES special observation near San Diego on June 7, 2007 showing high levels of ozone in the lower troposphere on the US side of the border

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Studying Carbon Monoxide and Ozone Plumes from Wildfires

• Examining the effect of the Esperanza Fire (10/26/2006) on tropospheric ozone using TES and other satellite instruments (OMI, MLS, AIRS)

• TES measures the vertical profiles of ozone and carbon monoxide down wind of the plume (Very large plume of CO)

• The use of satellite and surface monitor data to understand the evolution of ozone in the plume and **possible air quality implications.**

TES Step & Stare - RunID 5110
Ozone
Oct 26, 2006

TES Step & Stare - RunID 5110
CO
Oct 26, 2006

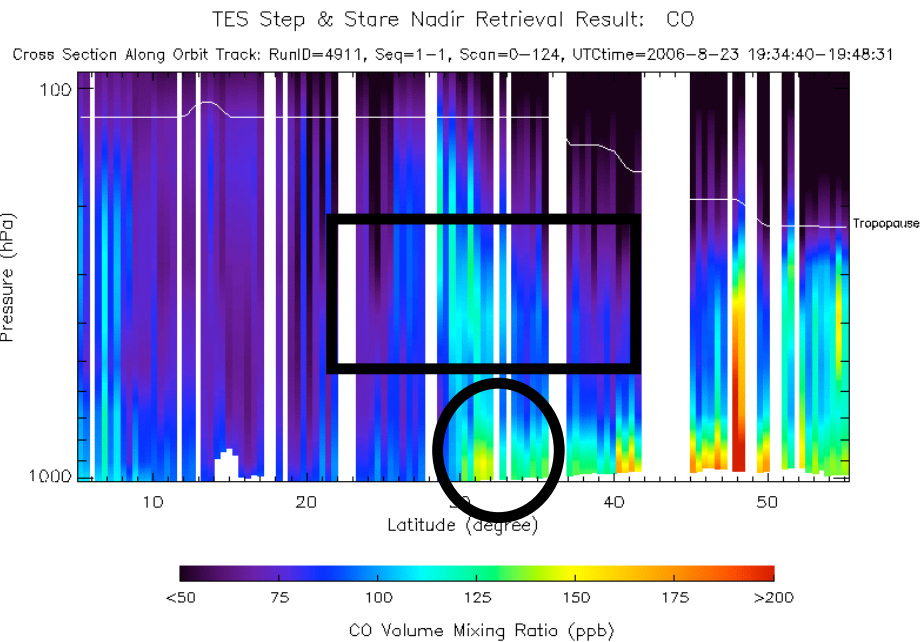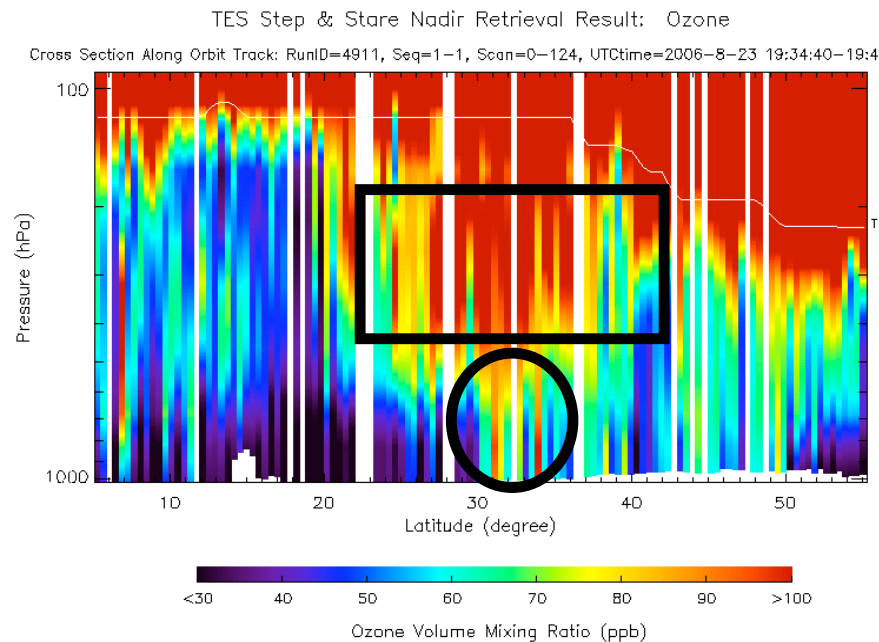Carbon Monoxide Plume

Texas Air Quality Study II

- Challenge in understanding the relative effects of local, regional, continental and global effects on air quality in Texas

- The Texas Air Quality Study II was a multi-institutional field campaign to provide the Texas Commission on Environmental Quality (TCEQ) with data that can be used in the development of ozone SIP revision

Ozone 1-Hour and 8-Hour Design Values for the HGB Area, and HGB Area Population (1991-2005)

$DV = (-2.9 * yr) + 215.31$
$R^2 = 0.7497$

$DV = (-0.87 * yr) + 117.94$
$R^2 = 0.3862$

125 ppb

85 ppb

Legend: 8-hour DV, 8-hour NAAQS, 1-hour DV, 1-hour NAAQS, population, Linear (1-hour DV), Linear (8-hour DV)
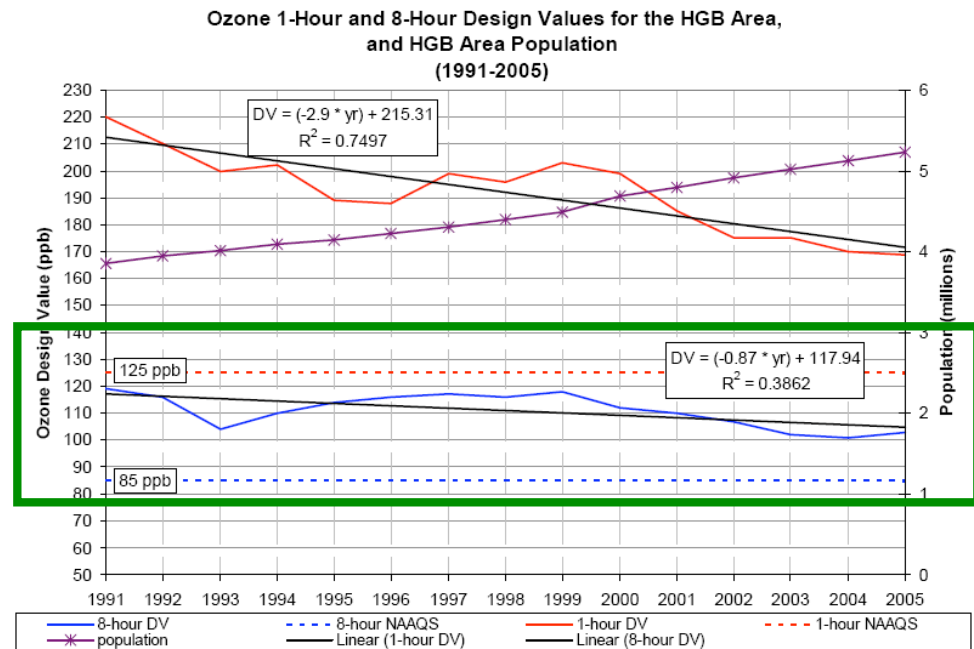
- TCEQ put together a list of specific questions to be addressed during the mission
- The mission featured quick turnaround of data and analysis and provided a final report (Rapid Science Synthesis) that provided answers to TCEQ questions
- The results of the Rapid Science Synthesis was used in the SIP revisions approved in May 2007
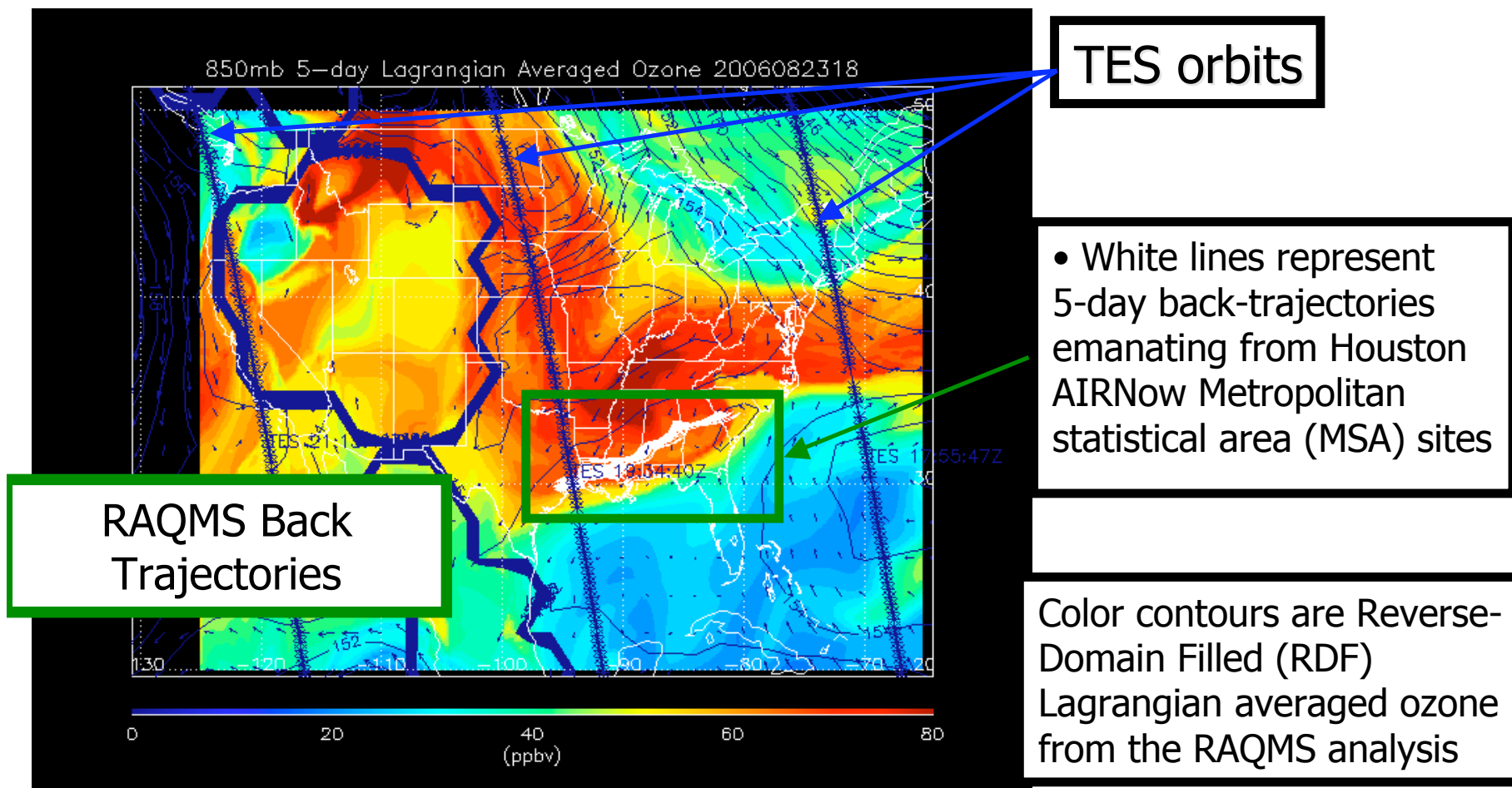- Increased participation of satellite data teams compared to TexAQS I (2000)

TexAQS Case Study – Aug 23, 2006

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Transport: Elevated CO and O3 over Houston region observed from TES Step & Stare on August 23, 2006 (TexAQS II)

TexAQS Case Study – Aug 23, 2006

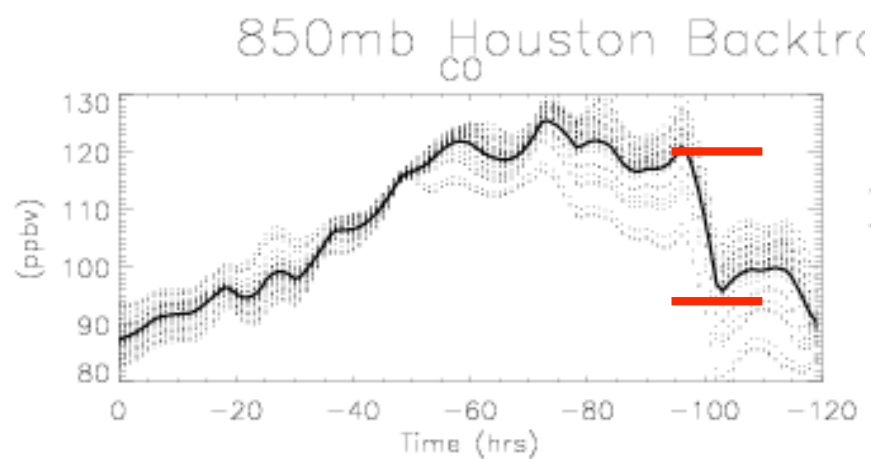

TES orbits

• White lines represent 5-day back-trajectories emanating from Houston AIRNow Metropolitan statistical area (MSA) sites

RAQMS Back Trajectories

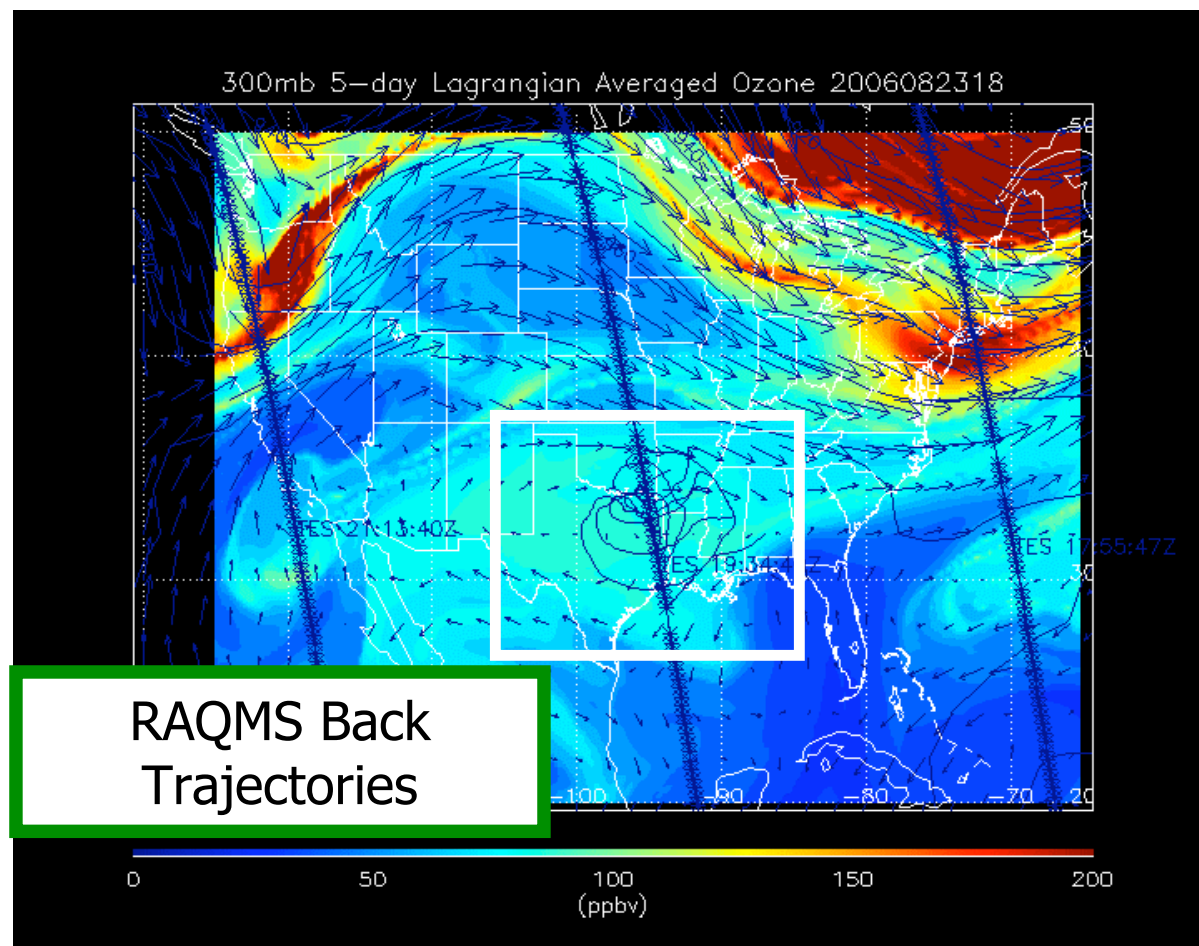Color contours are Reverse-Domain Filled (RDF) Lagrangian averaged ozone from the RAQMS analysis

TexAQS Case Study – Aug 23, 2006
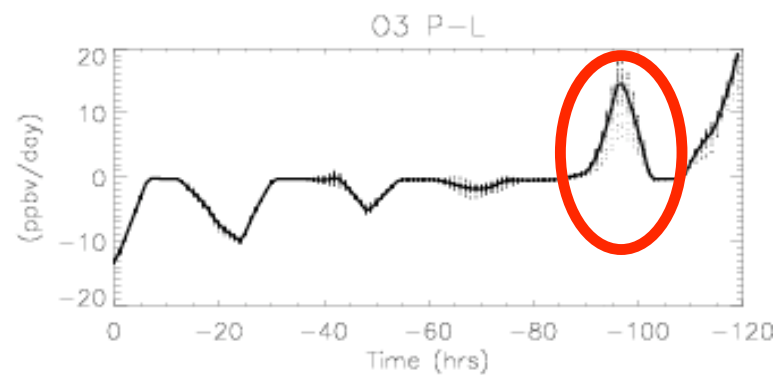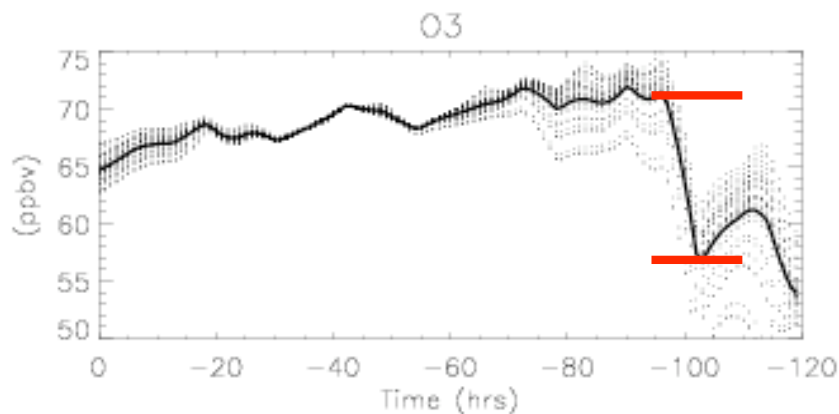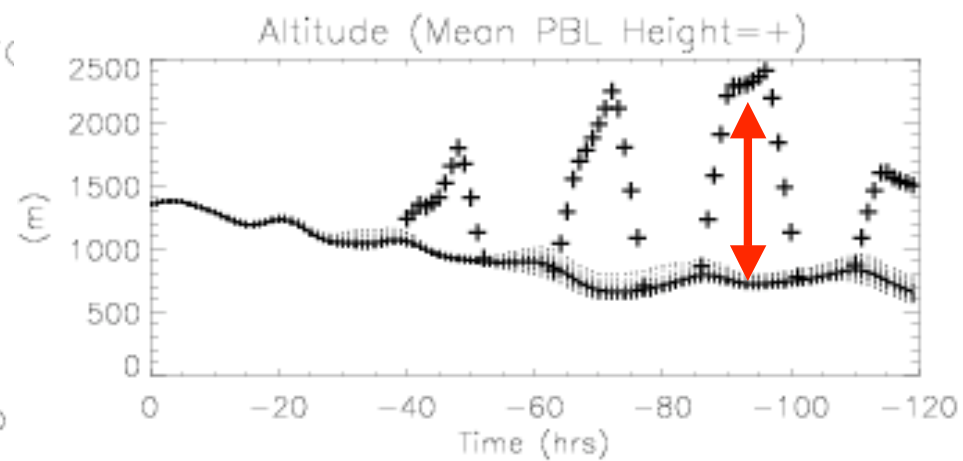
Ozone production in the boundary layer about 4 days prior to arrival in Houston

300mb 5-day Lagrangian Averaged Ozone 2006082318

RAQMS Back Trajectories

• Blue lines represent 5-day back-trajectories emanating from TES observations

TexAQS Case Study – Aug 23, 2006

• Ozone production in 48 hours prior to being observed by TES
• CO increases significantly 48 hours prior to being observed by TES
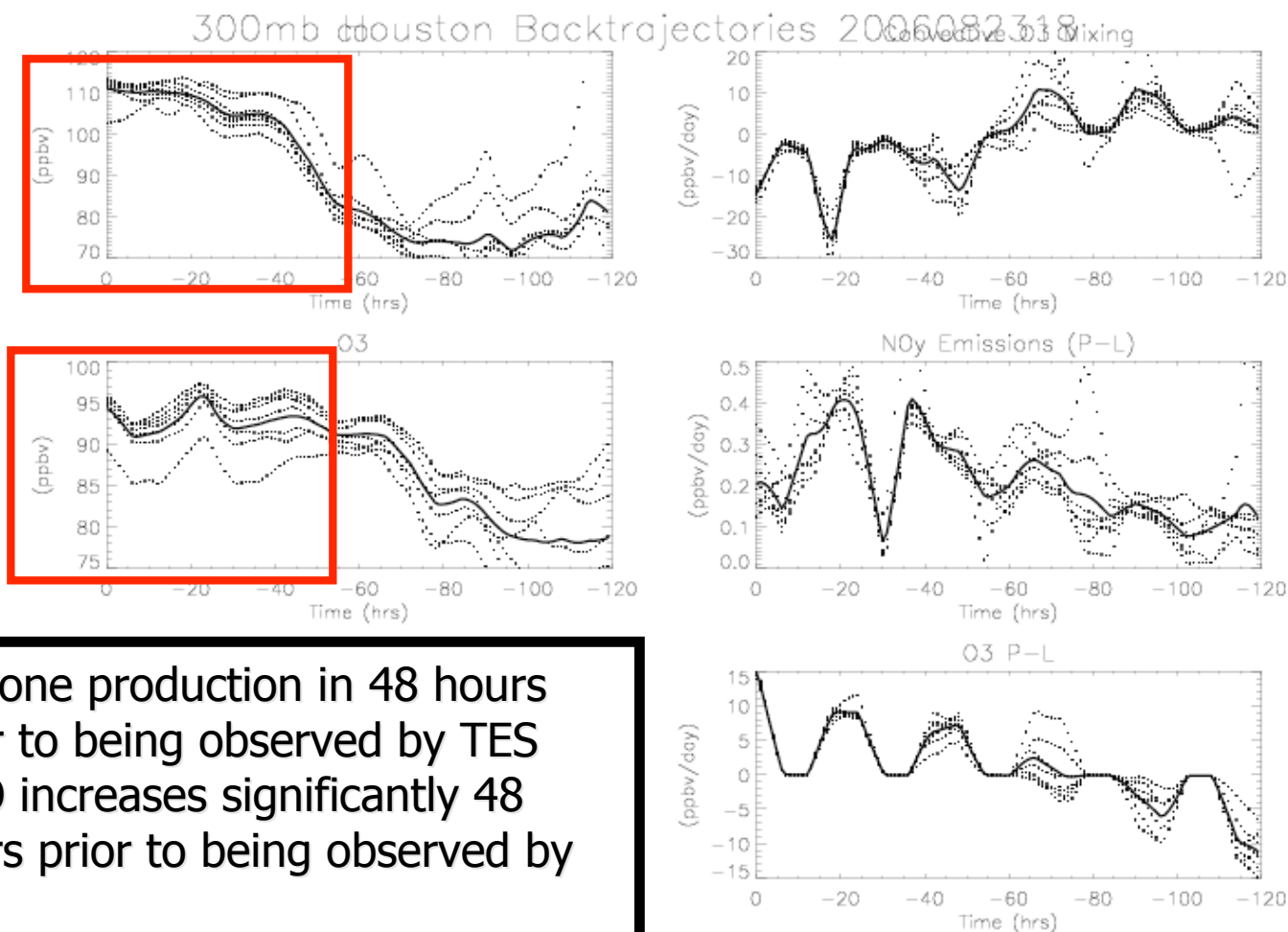
TexAQS Case Study – Aug 30, 2006

AIRS O3 Curtain along TES track: 20060830
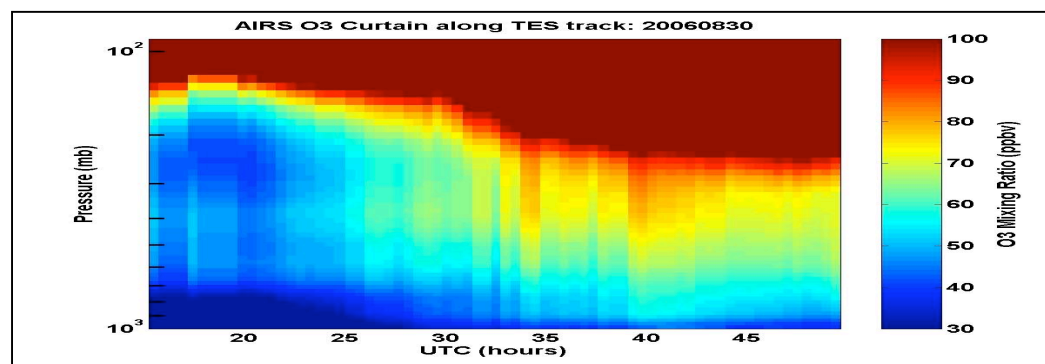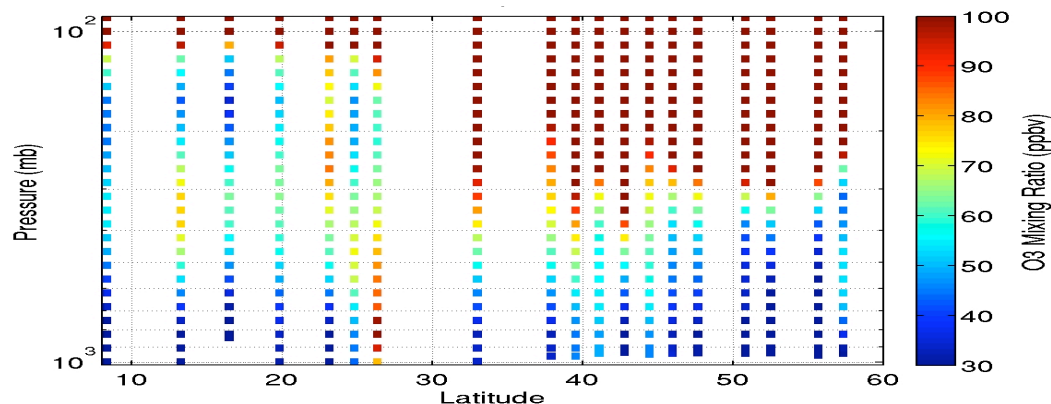
- Using AIRS, TES OMI data with RAQMS analysis
- AIRS, TES, MLS, and OMI provide consistent view of UTLS (CO, O_3, H_2O) on 30 August 2006 in TexAQS area
  - Track lower trop CO from fires to Houston
  - Stratospheric intrusion mapped
  - Possible pollution outflow from Houston into the Gulf
  - Possible lightning O_3